New Design for Reinforcing Steel - Pass Design of 3-sided Deformations

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Reinforcing steel is offered on the market as concrete steel bars, concrete reinforcing mats, lattice girders or wire rod in coils. The surface of the concrete reinforcing steels is usually provided with deformations (transverse protrusions) and in addition with ribs (longitudinal protrusions) to improve the compound behavior with concrete.

The production of rebar or reinforcement rods in hot rolling mills with 2-high stands is an established process. The 2-roll system creates the deformations in two or four rows. Three-row deformations are rather known from the production in cold rolling processes for standardized construction steel grades. However, in the past years, the changing market conditions have seen an increased demand for special grade construction steels, i.e. stainless high-grade steels. Because of the higher yield strength, it is challenging to create deformations in special grades so that the normal rebar plants often reach their design limits when the product range is extended or higher yields are required.

Within the Schmolz und Bickenbach group, Swiss Steel AG is the competence center for the production of special and free-cutting steels. Besides these main products, there is an increasing demand of the construction industry for profiled special grades, which are also produced in the combined bar and wire rod mill. This mill, which has been operating for approximately 30 years, has been continuously modernized and extended in the past 10 years (**Fig. 1**).

1. Situation at Swiss Steel AG

One of the important modernization measures was the commissioning of the 3-roll Reducing & Sizing Block (RSB) supplied by Friedrich Kocks GmbH & Co. KG (Kocks) in 2002, which was integrated in the finished mill to replace two 2-high stands. This investment allowed for the production of round and hexagonal bars with considerably higher productivity whilst also improving flexibility /1/. However, rebar made of special steel was still finish-rolled as bars using the common 2-high stands either upstream of the RSB for dimensions > 26mm or downstream of the RSB for dimensions ≤ 26mm.

Rolling of reinforcing steel bars thus meant a break in the pass design of the RSB and the known "1-pass family rolling". **Fig. 2** schematically shows the RSB-entry sections used to produce the product range of round bars 26.5 - 33.5mm and hexagonal bars 23.5 - 29.5mm. When making a production change to profiled grades of dimensions 30 and 34mm (P30/P34), the feeder sections in the intermediate mill have to be modified and the dummy passes of stand positions H14 and V15 have to be replaced by stands with special oval and finished passes. After final deformation, the material runs through dummy stands in the RSB onto the cooling bed. The deformed steel 26mm (P26) placed in the same rolling series is finished rolled in stand V19 after a roughing pass in the RSB. Besides considerably higher modification and setting efforts and less flexibility in dimension changes into the deformed steel bar ranges, the probability of potential trouble increases also. **Fig. 3** shows the increase of nonproductive time for rolling deformed steel bars compared to the average times for common round and hexagon dimensions Eight years after commissioning the RSB, the consequence was a mutual project with the company KOCKS to develop a future-oriented pass design of 3-sided deformed steel for stronger and corrosion-resistant reinforcing steels.

2. Requirements to the profile shape

Basically there are no clear and universally valid indications for the shape of the deformations and for the pass design for reinforcing steels. The worldwide applicable standards are country-specific. The draft of the European standard prEN 10080 generally defines the surface geometry of deformed steel bars in such a way that the products have two or more rows of deformations evenly distributed on the circumference /2/. Within each row, the spacing of the deformations has to be regular. There is no specification for the deformations. The deformation parameters are either to be determined by the related deformation surface or by a combination of distance, height and inclination or both (**Tab. 1**). This corresponds closely to the Swiss standard or other European standards. According to standard DIN 488-2 currently applicable in Germany, reinforcing steel bars have to have either two or four rows of deformations /3/.

Besides rather normative indications and possibilities, other requirements such as the possibility to machine the notches, process-technological aspects in the mill and post-processing at the customer have to be taken into account when selecting the pass design. The Swiss Steel AG decided for a profile shape according to DIN 488-2 with crescent-shaped deformations without longitudinal seams. The profile shape and cross-section of a 34mm reinforcing bar is shown in **Tab. 2**. The following aspects should be taken into account:

- Good machinability of the RSB rolls in the notch milling machine
- Simplification of the pass design and stable notch filling
- Online geometry measurement in the mill must be guaranteed

Furthermore, the bars produced through this process must be capable of being processed by the customers, including such as bending processes, production of screw connections or spiralled steel-reinforcement forms for concrete piers.

3. Pass design of 3-sided deformations

The profile shape preferred by the Swiss Steel AG corresponds to a rebar with oval core without ribs (Type OC0) in the Kocks nomenclature. Basically every cross-section shape of a 3-sided deformed or profiled bar can be divided into six basic types as shown in **Fig. 4**. In the first step, this classification differentiates the cross-section shape of the core as "oval" or the special case "round". Furthermore, there is either a longitudinal seam or rib, or the bar is profiled. It would also be possible to produce a bar with a triangular core, however this would lead to problems in bending processes, for example.

The classification presented here supports the coordination and finding of the individual, optimum geometry for the mill. Furthermore, it serves to evaluate the spreading behavior in the pass design and influences the dimensioning of the roll data.

The characteristic geometric parameters of the pass design are the core area (A_{Core}), which results from the core diameter (D_{Core}) and the core radius (R_{Core}), the height of the deformations (a_m) and the shape of the cross section of the ribs, if necessary (**Fig. 5**). In a first approximation, the pass adjusting data and the mass flow can easily be determined on the basis of these parameters independent from the shape and the direction of the deformations.

However, the shape, direction and spacing of the deformations influence the material flow during deformation in the pass depending on the rolling temperature and the steel grade of the rolled product. With a combination of unfavorable circumstances, there is a possibility of the deformations not being completely filled and not achieving the required standard minimum deformation height. Process technological experiences made with the production of 2- or 4-sided deformed reinforcing bars are comparable in this respect and, therefore, helpful.

The filling degree of the notches in the rolls is also influenced by the geometry of the ingoing bar cross section. The higher the rolled product enters into the finished pass, the higher the deformation can be formed[GED1]. The inscribed diameter of the free side at the bar after the roughing pass ($GT_{pre.finishing\ pass}$) must be considerably bigger than the circumference of the deformations (**Fig. 6**).

The admissible ingoing height is limited by two aspects:

1. When the bar becomes more triangular, it tends to twist in the pass. This would result in different heights in the quarter points of the deformations.

2. When the height of the entry cross section increases, the deformation degree in the finished pass increases and thus higher rolling forces are required. Therefore, a stand which is equipped with finished passes for deformed or profiled steels will be subjected to considerably higher laods than when rolling round material with the same nominal diameter.

Based on the results from two pre-tests made with the nominal dimension of 40mm, a pass design was prepared for the RSB allowing the Swiss Steel AG to roll reinforcing steels with nominal dimensions of 16 to 40mm as 3-sided deformed steel bars. This new pass design is shown in **Fig. 7**. Since the roughing pass in the Kocks RSB had to be adapted to the geometry of the finishing passes for reinforcing steel, the pass design for the roughing and finishing passes form a unit to roll the new finished product.

4. Integrated systems in the operating process

All known advantages of the RSB /4/ related to operation, such as

- Quick stand-changing concept (in the rolling mill)
- Quick roll changing system (in the rollshop)
- Computer–aided adjusting system for rolls and guides (in the rollshop)

- Remote adjustment of the rolls and guides (in the mill line)

are of course, applicable without any limitations for rolling deformed or profiled steels.

The known configuration program BAMICON (Bar Mill Configuration) from the company Kocks, which provides the operating data for the rolls, guide rollers, funnels and motor speed of the RSB, can also be used for rolling deformed and profiled steel bars by installing an update to the software.

Furthermore, the exact adjustment of the rolls is guaranteed in the rollshop by means of the pass adjusting system CAPAS (Computer Aided Pass Adjustment System) supplied by KOCKS. **Fig. 8** shows the stand of the RSB, equipped with rolls with the new roll pass design for deformed steel, in the CAPAS station. CAPAS recognizes the basic pass shape of the profiled rolls (**Fig. 9**) and supports the adjustment of the pass adjusting data provided by BAMICON before entering in the mill line. The application of the CAPAS-system to the profiled rolls in the rollshop is an important pre-requisite to reduce setting times. It was not necessary to modify the existing Swiss Steel AG CAPAS system for the introduction of the 3-sided deformed steel bars.

The company LAP GmbH (LAP) adapted the software of the existing 90RDMS-Swing for a possible online measurement of the profiles.

5. Operating results

5.1 Materials and dimensions

After the above-mentioned first two pre-tests, the pass design of 3-sided deformations was tested at different nominal dimensions of two special grades relevant for Switzerland (**Fig. 3**[GED2]). Besides the grade 17MnV7, which is mainly used in the area of concrete piers or masts with special requirements for rigidity and reinforcing flexibility, the grade X1CrNi12 has an increased corrosion resistance and is used, for example, in case of less overlap/coverage[GED3]. Both steel grades show yield strength of more than 700MPa and 500MPa.

5.2 Results in the rolling mill

Basically the transfer of calculations into the production process took place without problems for all examined dimensions and grades. The machining of the passes required some pre-tests until an optimum result was achieved by re-machining the notches. The installation of the rolls and the setup-settings in the production process did not show any negative effects. The temperature increase of the rolling strand, which usually occurs by the finished deformation steps could be eliminated almost completely by the pass design of 3-sided deformations.

The motor torques of the stand positions used in the RSB are shown as examples in **Fig. 10** for five billets of the pre-series of nominal diameter 34mm. The torque differs depending on the test situation of the mill. With the first billet, which was underfilled at first, the whole mill was broken in. Afterwards, settings were then optimized continuously. For the torque graphs, the high values of the roughing pass no. 3 (K3) have to be taken into account. It is typical for all dimensions and is caused by the pass design. The results showed that the filling of the notches in the last pass and thus the formation of the deformation height was very dependent on the ingoing rolled product. **Tab. 4** shows some effects on the geometrical data of the final product. All requirements for the 34mm reinforcing steel bar were met with the second billet. This applied to all dimensions. Only for nominal diameter 40mm, three tests were needed to achieve good results regarding the deformation height.

Fig. 11 shows the downtime in the mill after implementing the pass design of 3-sided deformations. Tremendous savings are already achieved for the set-up times, with the set-up time related to one steel dimension is reduced by 2/3 on average. Whether significant improvements can be achieved for adjusting and trouble times will depend on the production quantities in series production. Currently, Swiss Steel AG assumes the time saving indicated here.

5.3 Effects on post-processing

The effects on the changed design of the reinforcing steels were monitored for different customers and process steps. There were no adverse effects in bending processes, the production of hose connections or for pier reinforcements. (**Fig. 12**). The adaptations necessary for the approval in the index for concrete reinforcement steel in Switzerland are being checked. Finally, the design allows improved customer ties.

6. Summary

Within the Schmolz und Bickenbach group, the mill of Swiss Steel AG is the competence center for the production of special and free-cutting steels. Despite the investment in a 3-roll system from Kocks (RSB), profiled special grades have been finished-rolled in the conventional 2-high stands.

To simplify the pass design and thus to reduce the set-up and roll changing times, a future-oriented pass design was developed together with Kocks to allow rolling of reinforcing steels directly using the RSB. As with rolling with 2-high stands, the roughing and finishing passes form a unit in the 3-roll system.

The systems, which are integrated in the operating process were standardized for profiled bar and wire rod. The established configuration program BAMICON is quickly adapted with an upgrade of the software so that after input of the pass design for the deformed steel bars, the RSB can be configured reliably. It was not necessary to modify the RSB to produce "3-sided deformed reinforcing steel" at Swiss Steel AG.

The result was that deformed special grades can be produced especially well in a hot rolling process using an RSB. The operational test results of the 3-sided deformed steel bar from 16 to 40mm have already been very successful. The new pass design leads to an enormous shortening of the setting-up times. Tests in series are still missing and besides other optimization of the pass design, they are to show the potential for online measurement. The important final processing at the customers went without problems.

Swiss Steel AG has added a new 3-sided deformed "design" to the well-known product reinforcing steel. Besides continuous product and process improvements, lasting market pattern can only be achieved with innovation steps.

7. References

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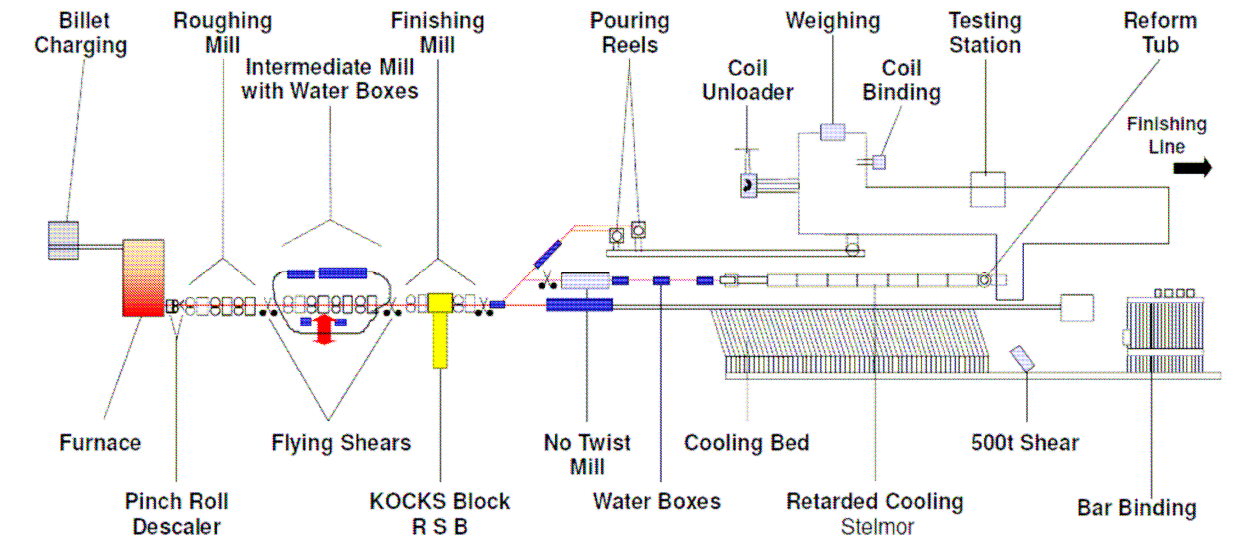


Technical data

Furnace capacity:	118t/h	Finish sizes:	Wire:	5.5-22.5mm Ø
			Bar in coil:	16.5–44.0mm Ø
Weight:	1.85t			17.7–37.5mm hex.
			Bar:	16.0-65.5mm Ø
Size:	150mm^2			17.7–62.0mm hex
			Deformed steel:	8.0-40.00mm

Abb. 1: Layout und technische Daten der einadrigen Stab- und Drahtstraße der Swiss Steel AG (SWST AG).

Fig. 1: Layout and technical data of the one-strand bar and wire rod mill of the Swiss Steel AG (SWST AG).

Stand	h x b (hot)				
Billet	152x152 mm				
H0					
~			~		
V7					
H8					
V9					
H10					
V11	ø 38			ø 41.5	
H12			Dummy		Dummy
V13			Dummy		Dummy
H14			Dummy		
V15			Dummy	P30	P34
K1 K2 K3 K4 K5	Kocks-Block RSB	Round	Hexagon		
H18					
V19		P26			
Finished size (cold)		ø 26.5 - 33.5 Deformed size 26	23.5 - 29.5	Deformed size shapes 30	34

Abb. 2: Schematische Darstellung des Kaliberschemas für gerippten Stahl über Duo-Gerüste bei SWST AG.

Fig. 2: Schematic presentation of the pass design for deformed steel bars on 2-high stands at SWST AG.

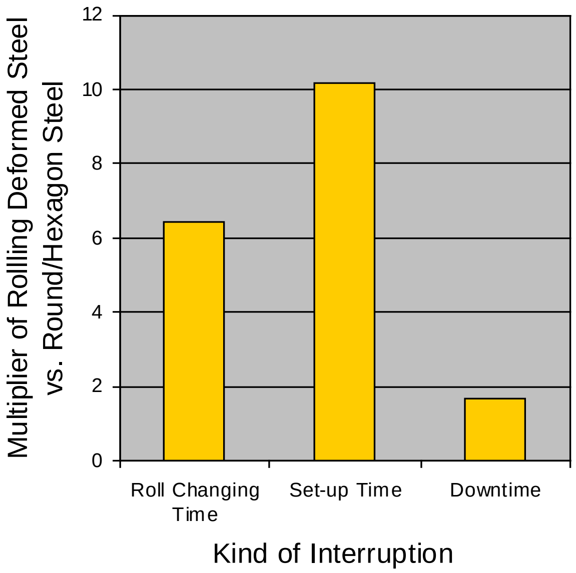


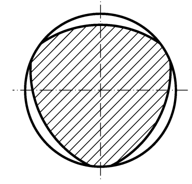
Abb. 3: Umstell- und Störungszeiten für Walzungen von geripptem Stahl im Vergleich zur Rund- oder Sechskantwalzung.

Fig. 3: Set-up time and downtime for rolling of deformed steel bars compared to round and hexagon rolling.

Tabelle 1: Anforderung an Rippenparameter nach DIN 488-2 /3/.
Table 1: Requirements on deformation parameters acc. to DIN 488-2 /3/

Nominal Size	Height (standard value)		Width	Spacing	Relative Area
d [mm]	Middle a_m [mm]	Quarter points $a_{1/4}$ and $a_{3/4}$ [mm]	*b* [mm]	*c* [mm]	f_R
16.0	1.04	0.72	1.6	9.6	0.056
20.0	1.30	0.90	2.0	12.0	0.056
25.0	1.63	1.13	2.5	15.0	0.056
28.0	1.82	1.26	2.8	16.8	0.056
32.0	2.08	1.44	3.2	19.2	0.056
40.0	2.60	1.80	4.0	24.0	0.056

Tabelle 2: Vorgaben der Profilform für einen 34mm Bewehrungsstahl bei der SWST AG.
Table 2: Specification of the profile shape for a 34mm reinforcing steel at the SWST AG.

Specification	Size [mm]	Nominal Mass g/m	Cross-Sectional Area [mm²]	Spacing [mm]	
max	33.3	7555	1332	23.46	
mean	**34.0**	**7127**	**1257**	**20.4**	
min	35.0	6842	1206	17.34	

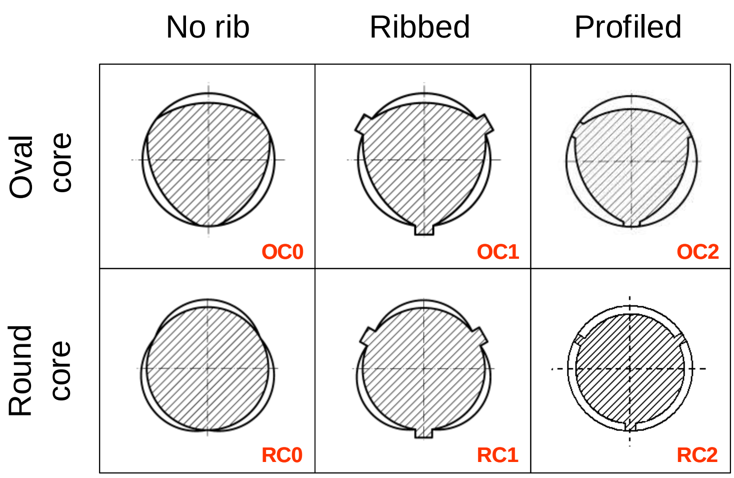


Abb. 4: Schematische Darstellung von Basisgeometrien für 3-seitig gerippte Stäbe im Querschnitt mit Kurzbezeichnung bei Kocks.

Fig. 4: Schematic basic geometries of cross-sectional area of 3-sided deformed bars with short description used in Kocks.

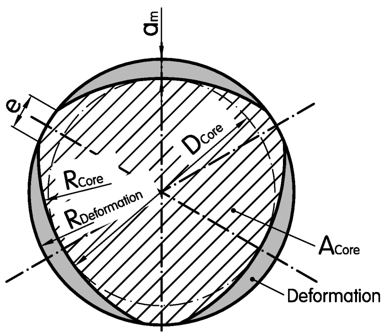


Abb. 5: Parameter eines 3-seitig gerippten Stabs mit ovalem Kern ohne Längsrippen.

Fig. 5: Parameter of bar with 3-sided deformations, oval core and without ribs.

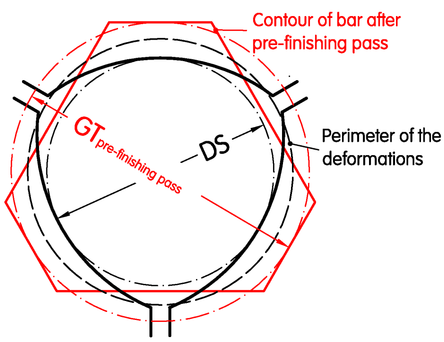


Abb. 6: Schematische Darstellung der geometrischen Verhältnisse im Fertigkaliber bei gerippten Stäben mit ovalem Kern.

Fig. 6: Schematic presentation of geometric situation in finished pass for reinforced bar with oval core.

Stand	h x b (hot)	
Billet	152x152	
H0		
~		~
V7		
H8		
V9		
H10		
V11	ø 38	
H12		Dummy
V13		Dummy
H14		Dummy
V15		Dummy
K1 K2 K3 K4 K5	Kocks-Block RSB	Round | Deformed size | Hexagon
Finished size (cold)		ø 26.5 - 33.5 | R1 26 | 30 | 23.5 - 29.5

Abb. 7: Das neue Kaliberschema für gerippte Stähle mit dem 3-Walzen Reduzier- & Sizing Block (RSB) bei SWST AG.

Fig. 7: The new pass design for deformed steel bars with the 3-roll Reducing & Sizing Block (RSB) at SWST AG.

Abb. 8: Gerüst des RSBs in der CAPAS-Station von Kocks mit eingebauten profilierten Walzen.

Fig. 8: Stand of RSB in the CAPAS station of Kocks with installed profiled rolls.

Abb. 9: Blick durch das Kaliber der profilierten Walzen.

Fig. 9: View into the pass with profiled rolls.

Tabelle 3: Überblick über Abmessungen und Werkstoffe für die Kalibrierungsversuche.
Table 3: Overview on dimensions and materials for the pass design tests.

Nominal diameter / Quality	16, 18, 20 and 22 [mm]	26, 30, 34 and 40 [mm]
17MnV7		X
X2CrNi12	X	26mm

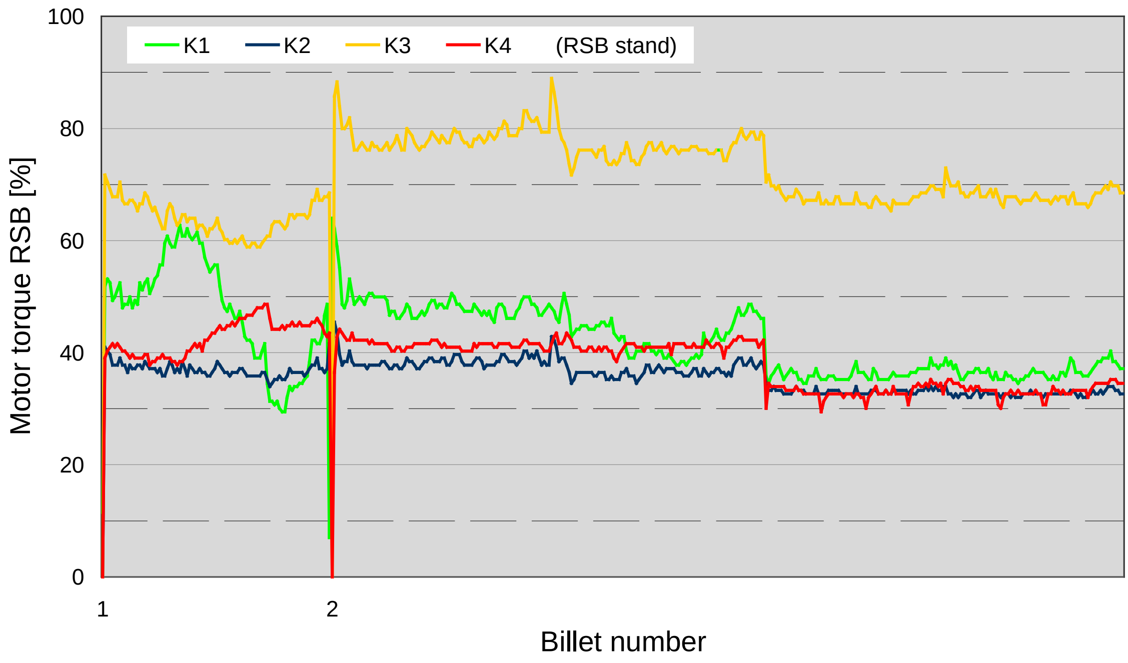


Abb. 10: Motormomente der RSB-Gerüste eingesetzt für die Nennabmessung 34mm.

Fig. 10: Motor torque for the RSB stands used for the nominal dimension 34mm.

Tabelle 4: Parameter des 3-seitig gerippten Stabs der Nennabmessung 34mm mit
DT = eingeschriebener Kreis der gewalzten Seite und
GT = Umkreis der freien Seite gemessen am Stab.

Table 4: Parameter of the bar with 3-sided deformations of the nominal dimension 34mm with
DT = inscribed circle of the rolled side and
GT = circumference of the free side measured at the bar.

Parameter		Actual	Target
(GT+DT)/2 from 2 Point Measurement	[mm]	35.86	
GT	[mm]	35.21	max.36.6
Height of Deformation (a_m)	[mm] [mm]	2.08 2.38	2.2 ± 0.2
DT	[mm]	36.51	min. 35.0
Nominal Weight	[g/m]	7162	7127
Nominal Diameter	[mm]	34.08	34.0

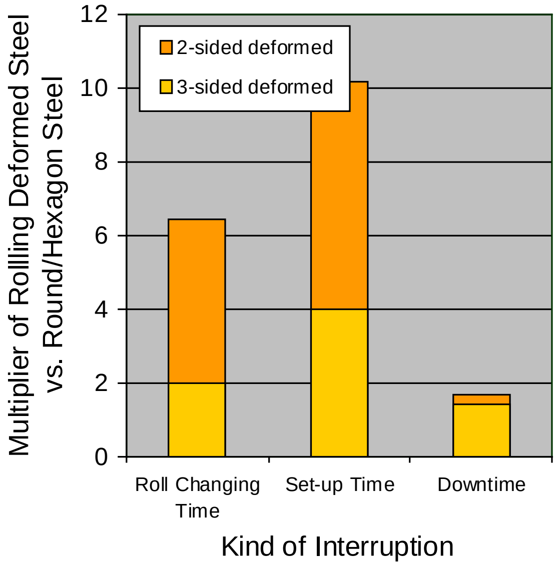


Abb. 11: Bereits umgesetzte und erwartete Verbesserung der unproduktiven Zeit.

Fig. 11: Already implemented and expected improvements of unproductive time.

Abb. 12: Spiralanfertigung von Mastbewehrungen.

Fig. 12: Spiralled steel-reinforcement for concrete piers.